Gluon Propagator in Maximally Abelian Gauge and Abelian Dominance for Long-Range Interaction

K.Amemiya and H.Suganuma
Research Center for Nuclear Physics (RCNP), Osaka University
Mihogaoka 10-1, Ibaraki, Osaka 567, Japan
E-mail: amemiya@rcnp.osaka-u.ac.jp

We study the gluon propagator in the MA gauge with the lattice QCD Monte Carlo simulation. The simulation is performed using the heat-bath algorithm on the SU(2) lattice with $12^3 \times 24$ and $\beta = 2.3, 2.35$. The propagator of the off-diagonal charged gluon behaves as the massive gauge boson and provides the short-range interaction, while the diagonal gluon propagates long distance. This is the origin of the abelian dominance in the long-range physics.

1 Introduction

The analogy between the QCD vacuum and the superconductor is an interesting current topics for the study of the confinement mechanism [1].

The key point is the use of the maximally abelian(MA) gauge, because QCD reduces into the abelian gauge theory including QCD-monopoles [2]. Remarkably, in the MA gauge, the diagonal part of gluon field plays a dominant role to the nonperturbative quantities like confinement and chiral symmetry breaking [3]. On the other hand, the off-diagonal part of gluon field behaves as a charged matter field and does not contribute to the long-range phenomena. This is called as the abelian dominance [4]. The abelian dominance is confirmed by the recent lattice QCD simulation [5]. However, the origin of the abelian dominance in the MA gauge is not understood yet.

As a possible physical interpretation for the abelian dominance, the effective mass of the charged gluon may be induced in the MA gauge, and therefore the charged gluon propagation is limited within the short-range region because the massive particle propagates within the inverse of its mass. Here, we study the gluon propagator [6] in the MA gauge in terms of the interaction range and strength using the lattice QCD Monte-Carlo simulation.

2 Maximally Abelian (MA) Gauge

In the lattice QCD, the MA gauge is defined by maximizing $R_{MA} \equiv \sum_{s,\mu} \mathrm{Tr}\left[U_\mu(s)\tau^3 U_\mu^\dagger(s)\tau^3\right]$ using the SU(2) gauge transformation. In the MA gauge, the SU(2) link variable $U_\mu(s)$ becomes U(1)-like due to the suppression of the off-diagonal component. As for the residual U(1) gauge

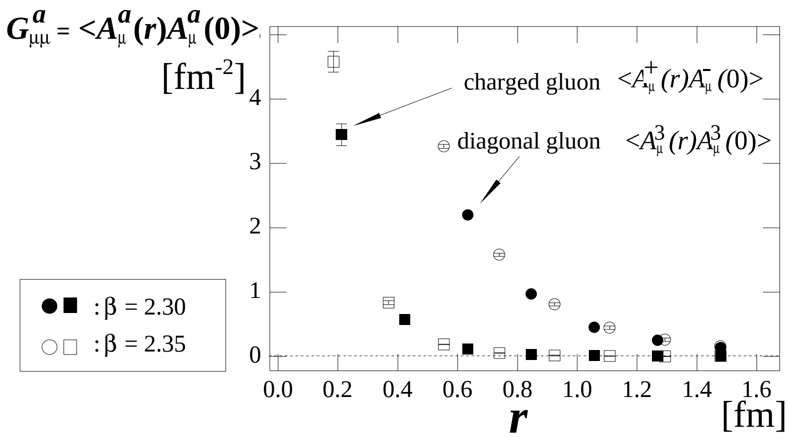

Figure 1: The gluon propagator in the MA gauge. In the MA gauge, the only diagonal-gluon is dominant in the long-range region, $r \gtrsim 0.4$ fm.

symmetry, we impose the U(1) Landau gauge fixing to extract most continuous gauge configration and to compare with the continuum theory.

3 Lattice QCD Results for Gluon Propagator

We calculate the gluon propagator in the MA gauge by the lattice QCD Monte Carlo simulation, particularly considering the scalar combination of $G^a_{\mu\mu}(r) \equiv \sum_{\mu=1}^4 \langle A_\mu{}^a(r) A_\mu{}^a(0)\rangle$ $(a = 1, 2, 3)$.Here, the scalar combination $G^a_{\mu\mu}(r)$ is useful to observe the interaction range of the gluon, because it depends only on the four-dimensional Euclidean radial coordinate $r \equiv (x_\mu x_\mu)^{\frac{1}{2}}$.

In Fig.1, in the MA gauge, the off-diagonal (charged) gluon propagates within the short-range region $r \lesssim 0.4$ fm : the charged gluon behaves as the massive particle and does not contribute to the long-range physics in the MA gauge. On the other hand, the diagonal gluon propagates over the long distance and influences the long-range physics. Thus, we find the abelian dominance for gluon propagator that the only diagonal gluon field is relevant for the long-range physics in the MA gauge. This is the origin of the abelian dominance for the long-range physics.

The off-diagonal (charged) gluon propagator decreases more strongly than the massless gauge-boson propagator $G_{\mu\mu}(r) = \frac{3}{4\pi^2}\frac{1}{r^2}$. Therefore, the charged gluon is expected to have an effective mass in the MA gauge. We estimate the effective mass of the charged gluon from the scalar combination $G_{\mu\mu}(r)$ of the gluon propagator. Since the propagator of the massive gauge boson with mass

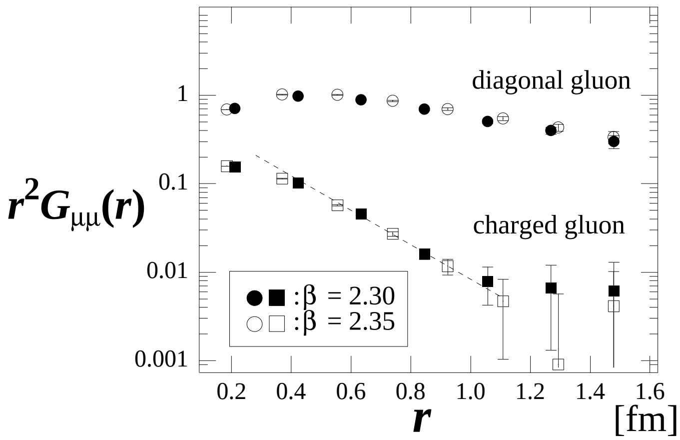

Figure 2: The logalithmic plot of $r^2 G_{\mu\mu}(r)$ as the function of the distance r in the MA gauge. The charged gluon propagator behaves as the Yukawa-type function, $G_{\mu\mu}(r) \sim \frac{\exp(-Mr)}{r^2}$. The effective mass of the charged gluon can be estimated by the slope of the dotted line.

M behaves as the Yukawa-type function $G_{\mu\mu}(r) = \frac{3}{4\pi^2}\frac{1}{r^2}\exp(-M\ r)$, we can estimate the effective mass of gluons $M_{\rm eff}$ from the slope of the logalithmic plot of $r^2 G_{\mu\mu}(r) \sim \exp(-M_{\rm eff}\ r)$. In Fig.2, the charged gluon correlation $r^2 G_{\mu\mu}(r)$ decreases linearly in the long-range region $r \gtrsim 0.4$ fm. We obtain the effective mass of the charged gluon from this slope in the intermediate region $r = 0.35 \sim 1.0$ fm as $M_{\rm eff} \approx 4.5\ {\rm fm}^{-1}\ = 0.9$ GeV .

To summarize, the effective mass of the off-diagonal (charged) gluon is induced as $M_{\rm eff} \simeq 1$ GeV in the infrared region in the MA gauge. Accordingly, the off-diagonal gluon can be neglected and does not contribute to the long-range physics as $r \gtrsim 0.4$ fm, although its effect appears in the short distance as $r \lesssim 0.4$ fm. Thus, only the diagonal gluon propagates the long distance, which leads to the origin of the abelian dominance for nonperturbative QCD.

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